MAPS Project Details

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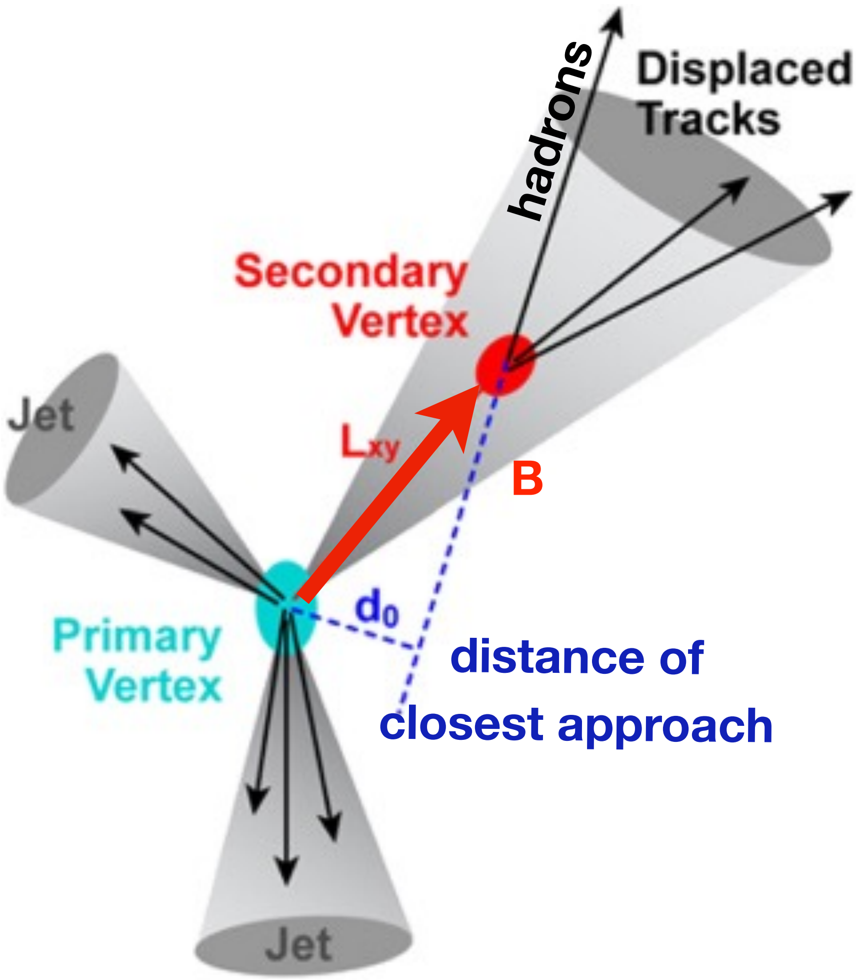
sPHENIX Tracking Meeting
November 20th 2015

B-jet Identification Reminder



sPHENIX should have access to 3 different techniques for heavy-flavor identification:

(1) Semi-leptonic decay

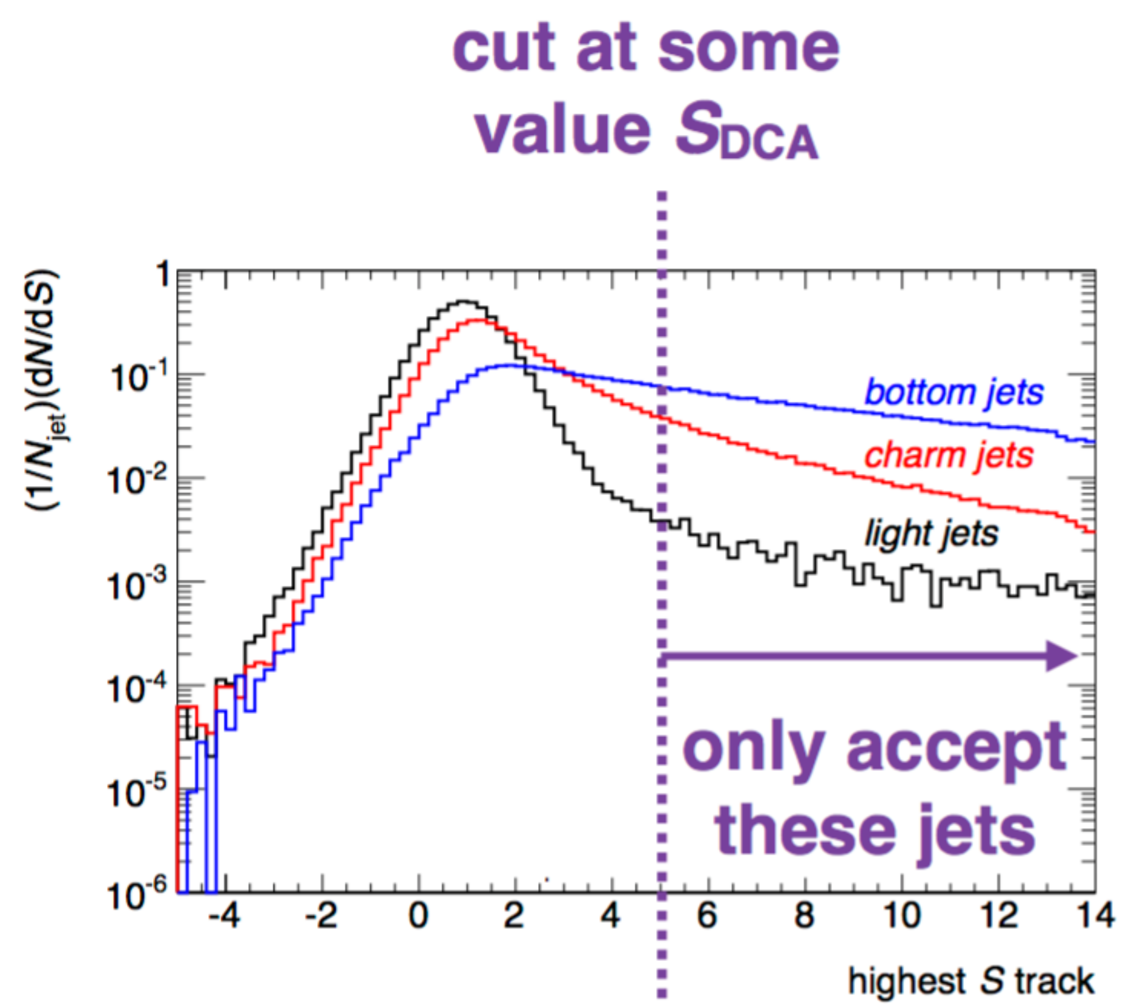
(2) Multiple Large DCA tracks

(3) Secondary Vertex Mass

Track Counting requirements:

Large single particle reconstruction efficiency, $\sim\epsilon^N$

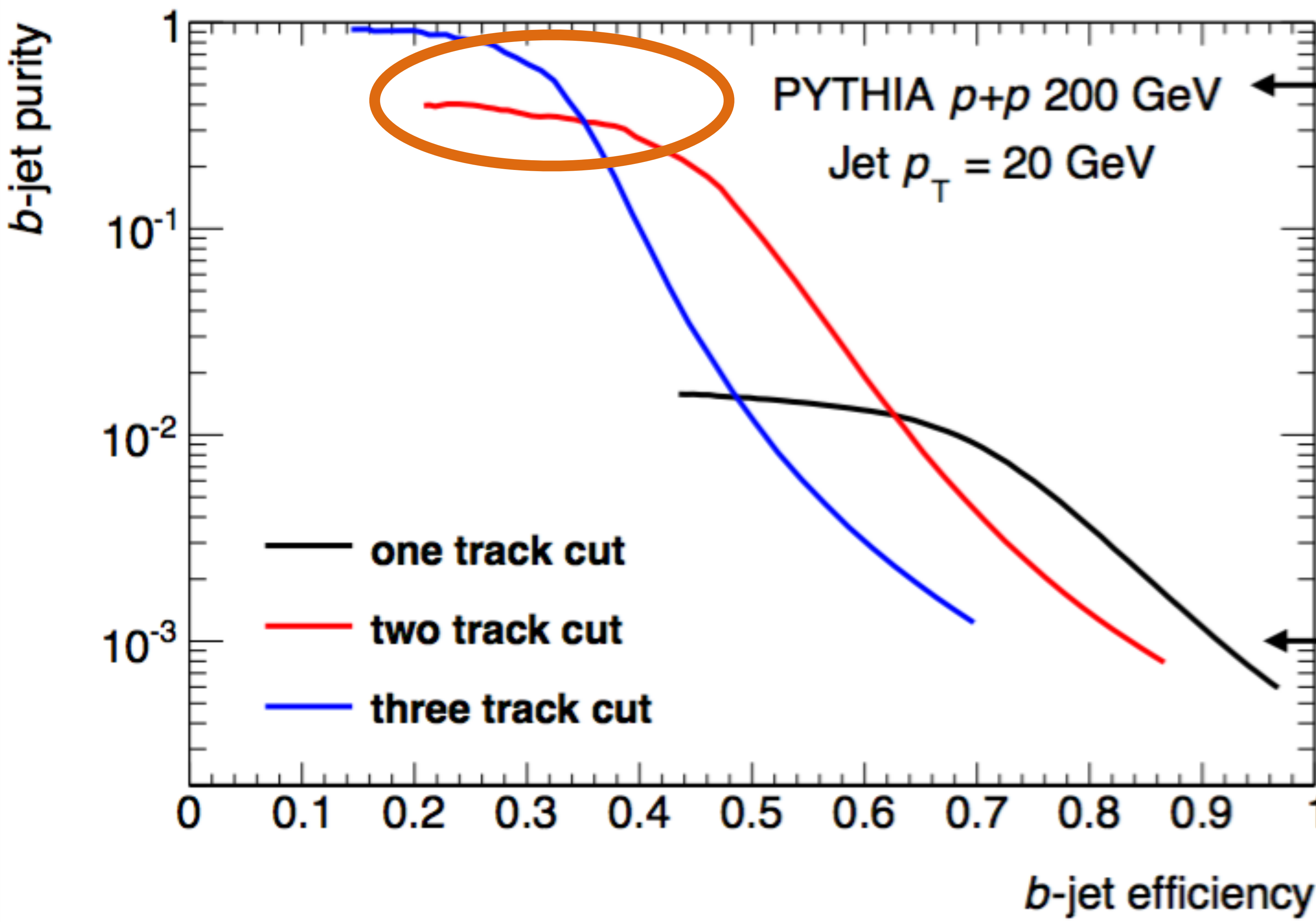
Narrow primary hadron DCA distribution (<70um)



B-jet Identification Reminder

from the April Review…

b-jet performance in *p*+*p*



Purity ~ 0.5 is achievable at reasonable efficiency!

Purity <10^{-3} before any cuts!

P vs. **E** curves for requiring **1**, **2** or **3** tracks with S_{DCA} above some minimum value

12

Trac

La

e

Na

14

highest S track

LDRD Description

(1) ER (Exploratory Research) - smaller funding level

3 years at <$300K / year (support level variable with federal budget)

Typically a fraction of a staff FTE and a postdoc, 1.5 FTE

Small effort on a large project (LHCb heavy ions)

Low cost hardware development (Dark Photon trigger paddles for E906)

Theory development (RHIC B-jet calculations + B-jet id algorithm)

(2) DR (Directed Research) - larger funding level

3 years at <$2M / year (acceptance rate is variable with federal budget)

Should support a team of people 4-5 FTE, only ~25% fraction for equipment

Advanced detector prototyping or full construction (iFVTX prototype, E1039 target)

Proposals are judged on:

scientific output, innovation, leadership, multi-discipline component, long term support

Previous DR Attempt: Key Deliverables

Our strategy: Lightweight O(0.5) DR support level to balance long lead time to sPHENIX (outside 3 years, sPHENIX not reviewed at initial submission)

Experimental Component (1.5 FTE, $660K for materials):

> “The primary experimental goal of this project is to **develop and validate with a test beam prototype** a technology suitable for the innermost tracking layers needed to perform the most challenging of the inner tracking tasks—the bottom jet identification—as well as serve the needs of the larger light jet and upsilon program.”
>
> > Aside: the secondary experimental goal overlaps with the b-jet id development for sPHENIX (part of my time dedicated to that task)

Theory Component (0.5 FTE):

> “A primary theoretical objective of this project is to develop **new strategies for prompt b-jet identification** with the proposed sPHENIX detector, and **present accurate theoretical predictions** for b-jet observables and their modification in the ambiance of the QGP at RHIC.”

Outcome: only rejected at last round, viewed as “not our year”, this year we compete with Astro

Encouraged to expand the project and resubmit this year

Private response from committee member “strong project, essentially no criticism”

Current Effort and LDRD plan

Independent of LDRD, we are acquiring some MAPS sensors and readout card

Our LDRD strategy (under deliberation): Ask for Full DR support level to due to shorter development time remaining and very positive previous review and seriousness of sPHENIX project has greatly improved

Push harder on our divisions to highly rank the project

Adding senior PIs (e.g. Ivan Vitev)

Experimental Component (3 FTE, ~$800K for materials):

- Goals: develop and test a prototype tracker + bjet id 2nd vertex
- add: develop and prototype hardware needed for DAQ integration (FEMs)
- add: engineering design for sPHENIX tracker options (inner MAPS, full MAPS)

Theory Component (1.5 FTE):

- Goals: theory predictions for RHIC, strategies for b-jet id
- add: overlap with WDM plasma physics

prepare the MAPS option for immediate execution by non-LDRD funding by 2018

Project Path to sPHENIX install

So the immediate question I expect from you is where could we secure additional funds for the detector implementation?

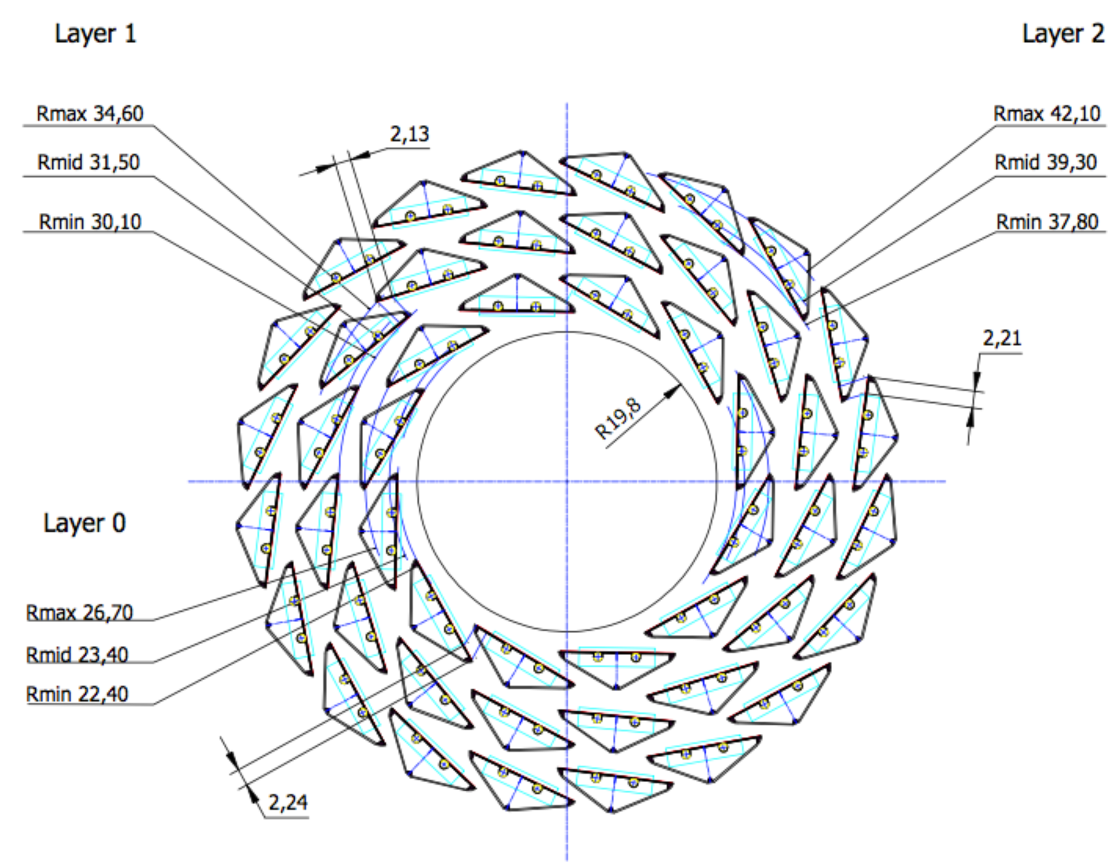
As a first option, I plan to submit a **DOE early career proposal** before I age out in 2019 to build the inner MAPS barrel and rescue the sPHENIX bottom jet physics:

Extend the production of the ALICE ITS inner staves (27 cm long), in discussions with LBNL and Korean inst.

ALICE ITS cost is 11M USD in FY15 (convert to USD and scale for inflation)

Down-scaling by area gives unreasonably small figures, so I scale by number of ladders and get **1.5 M USD** for reimplementing the inner 3 layers (<5 cm)

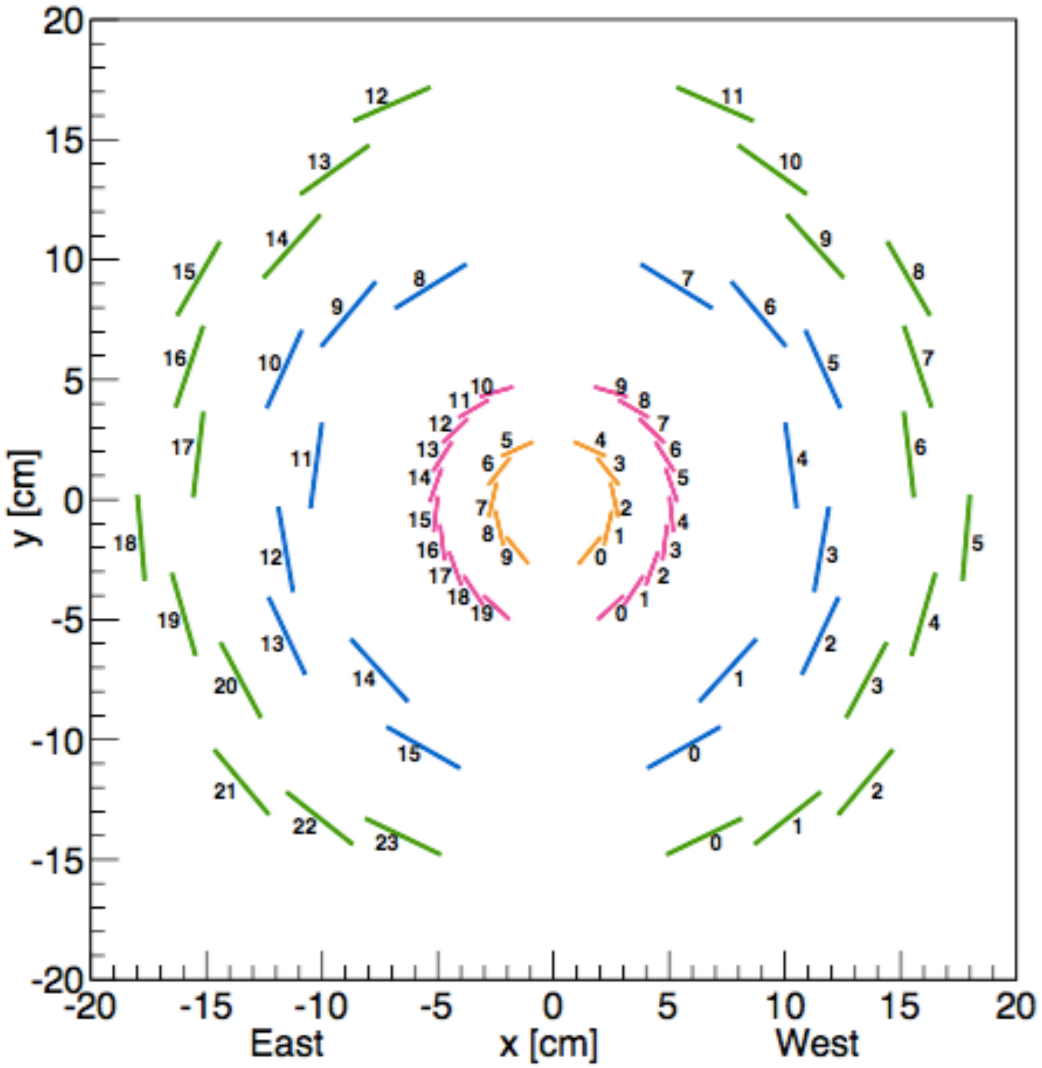
Within the funding profile of early career support, could also seek direct funding from DOE if unsuccessful



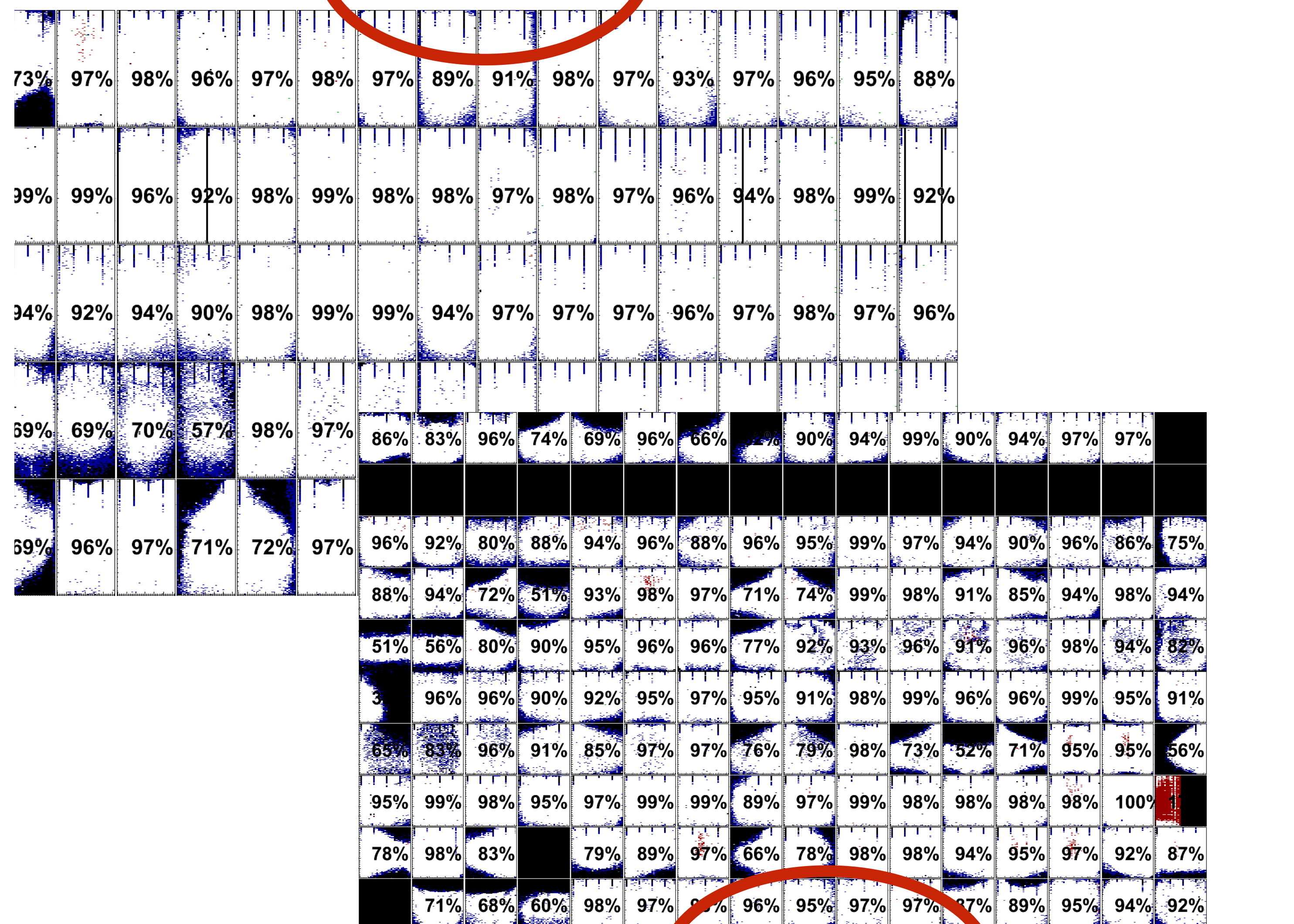
Main roadblock for full MAPS detector is the outer radius estimate is ~60 cm, resulting in a O(15M) USD scale project, could be funding from DOE, but without reuse in the EIC I have reservations about the viability of that proposal

BACKUP SLIDES

Tracking Option: Pixels



Pixel Layer 1, 92.5% Active



Pixel Layer 2, 72.5% Active

Station	Layer	radius (cm)	pitch (μm)	sensor length (cm)	depth (μm)	total thickness X_0%	area (m^2)
Pixel	1	2.4	50	0.425	200	1.3	0.034
Pixel	2	4.4	50	0.425	200	1.3	0.059
S0a	3	7.5	58	9.6	240	1.0	0.18

Other Potential Pixel Reuse Pitfalls

Material thickness (1.3% per layer):

More clear now that with the strip outer layers the material in the inner layers isn't a driver on the Upsilon separation, we should repeat that with the TPC option

Long term evolution will still replace the pixels

One-dimensional optimization in pitch (50um x 425um):

VTX pixels were designed around a DCA-based analysis

Two track intersection probabilities needed for 2nd vertex reconstruction need to be understood

Can the VTX pixels perform the 2nd vertex reconstruction at all?

DAQ Rate:

VTX pixel test saw 14 kHz at 60% live time, somewhat under our 15 kHz ~90% live time readout spec

New hardware could design in the full readout bandwidth

Not sure where the next bottleneck would be, more than a small gain?

Limited TPC integration flexibility:

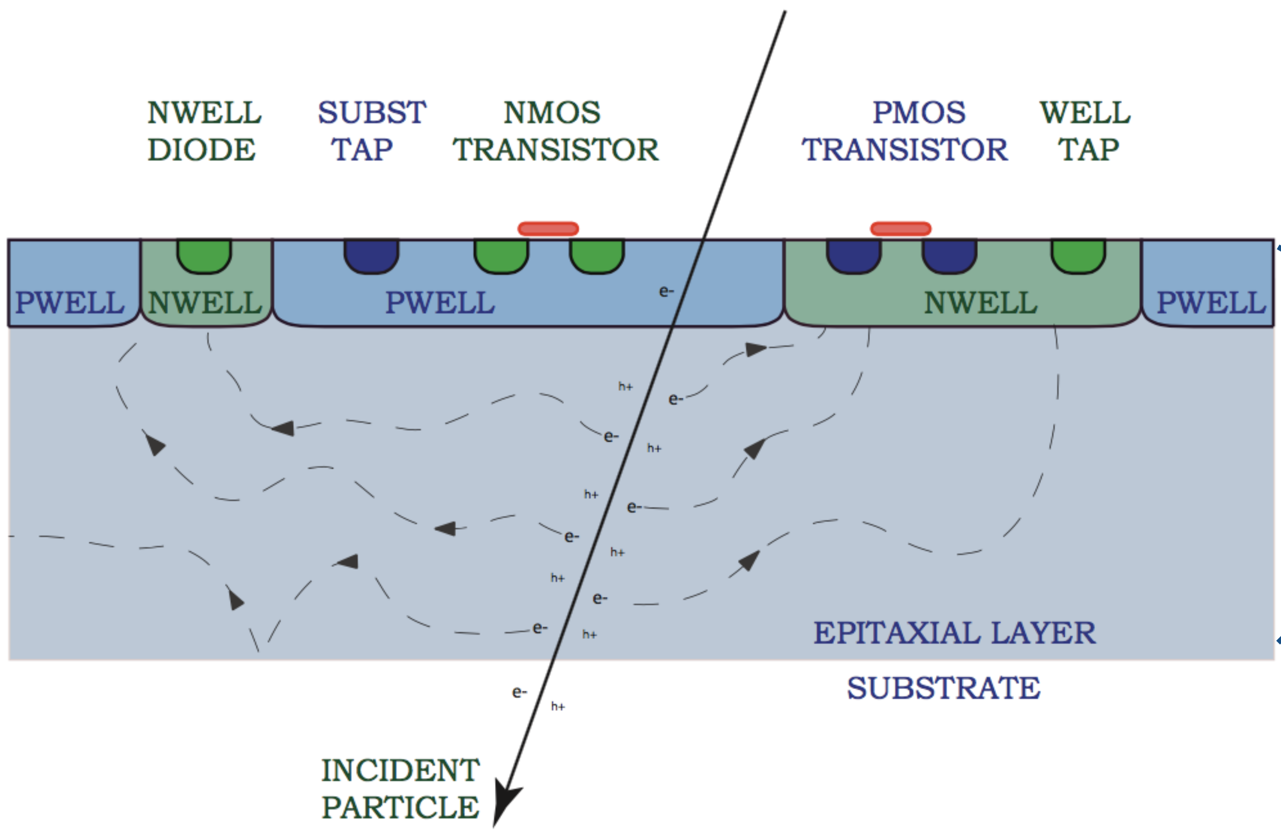
A finite surface area of VTX pixels is available, we can cover 2.4 cm and 4.4 cm

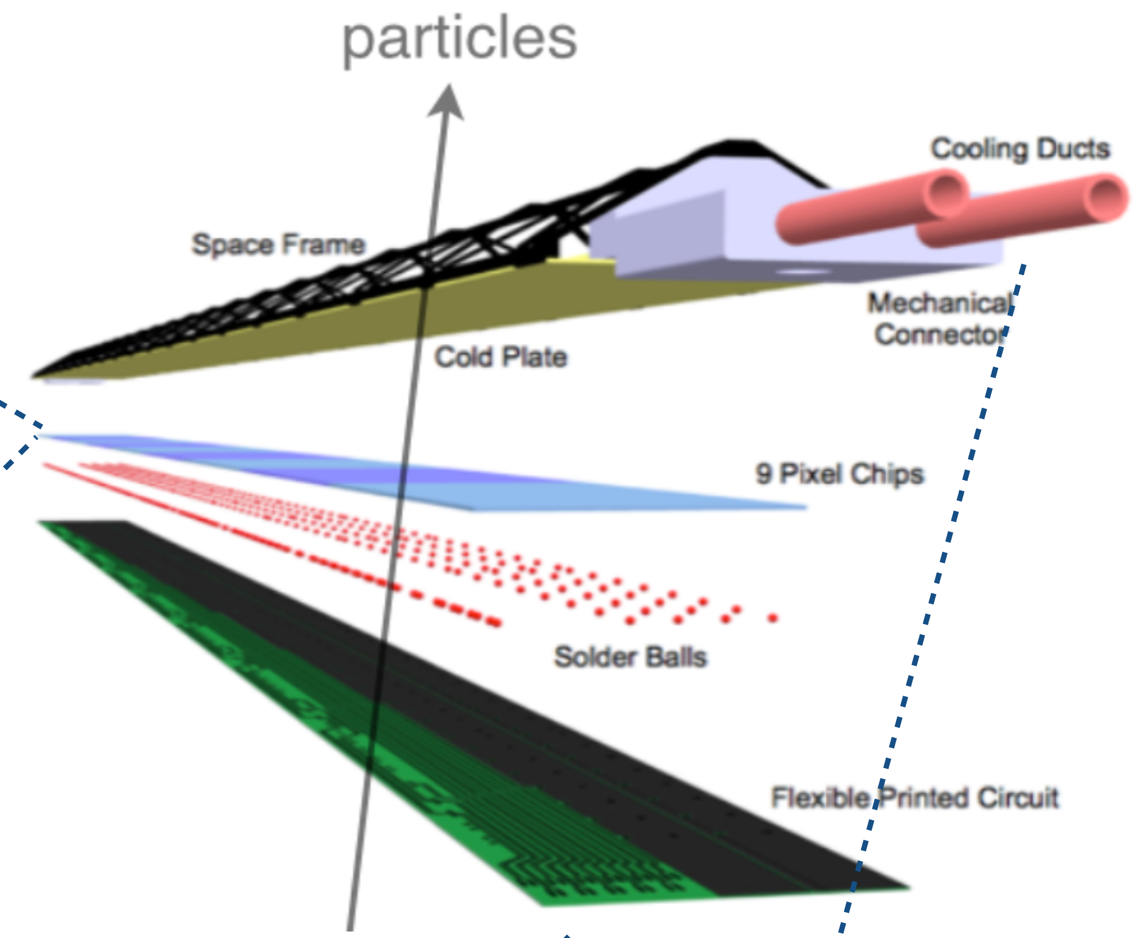
TPC based tracking starts no closer than 30 cm

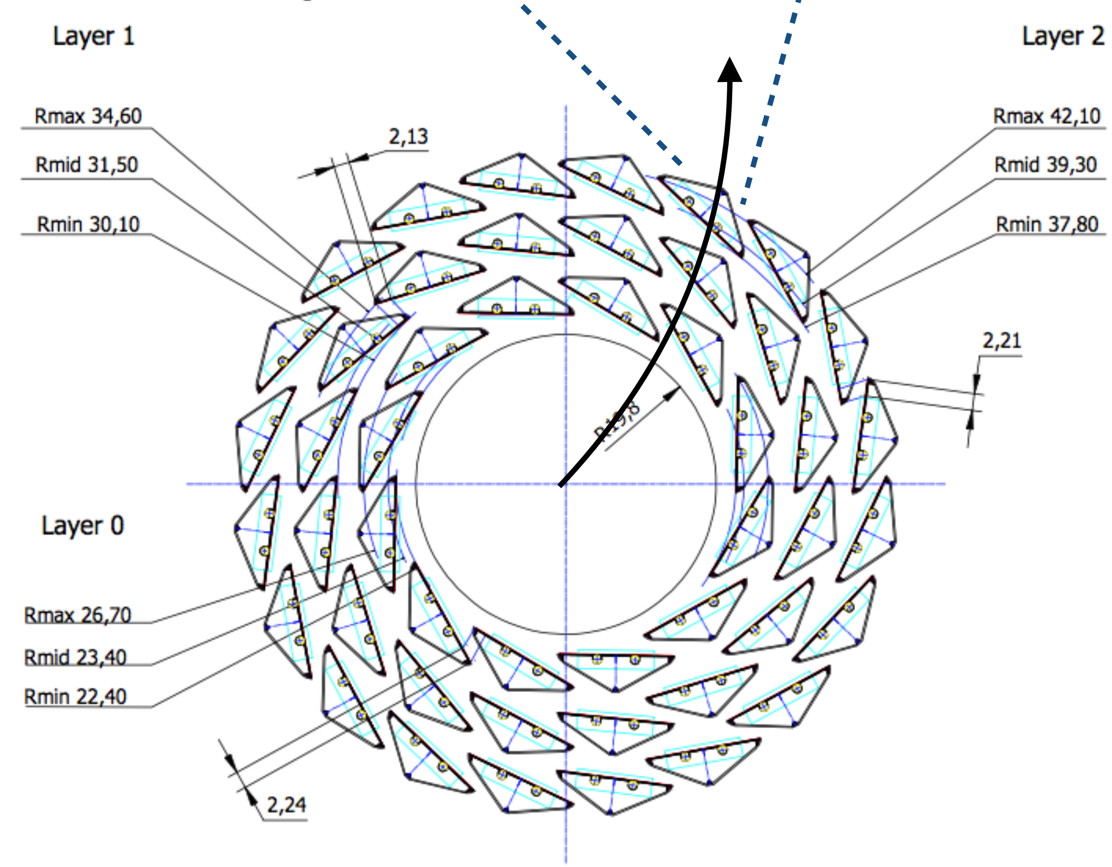
4.4 cm to 30 cm is a long jump to make

We may need a tracking layer between 4.4 and 30 cm to break ambiguities in the tracking

Tracking Option: MAPS sensors







Inner Silicon Concept:

Thin, fine pitch (<30 um), large efficiency

Optimizations for material thickness, ~0.3%/layer

Integration time: ~2-4 us

Goal:

Precision tracking & vertexing for b-jet identification and other tracking duties

Opportunity:

Reuse thin inner tracking layers during the EIC era

MAPS Geometry

from the pCDR:

Layer	radius (cm)	pitch (μm)	sensor length (μm)	depth (μm)	total thickness $X_0\%$	length (cm)	area (m^2)
1	2.4	28	28	50	0.3	27	0.041
2	~4	28	28	50	0.3	27	~0.068
3	~6-15	28	28	50	0.3	~27-39	~0.102-0.368

3 layers will probably be needed to define the track position and curvature for a 2nd vertex reconstruction, can be done within the material cost of 1 VTX pixel layer

Similar inner layer positioning, just outside our beam pipe

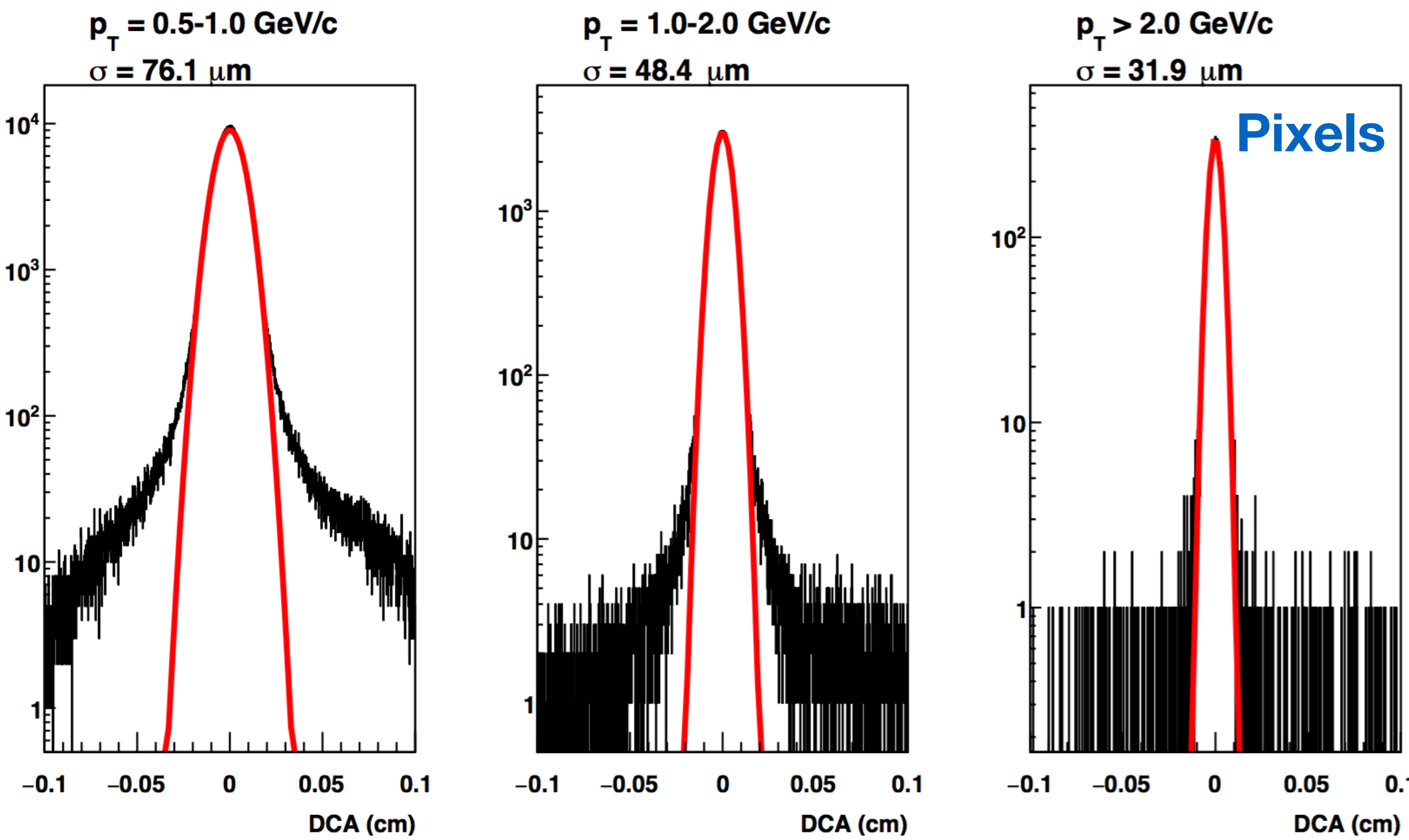
Outer staves could sit as far as 6 cm from the beam pipe before a longer than 27 cm ladder arrangement is needed—as dictated by vertex⊗eta coverage.

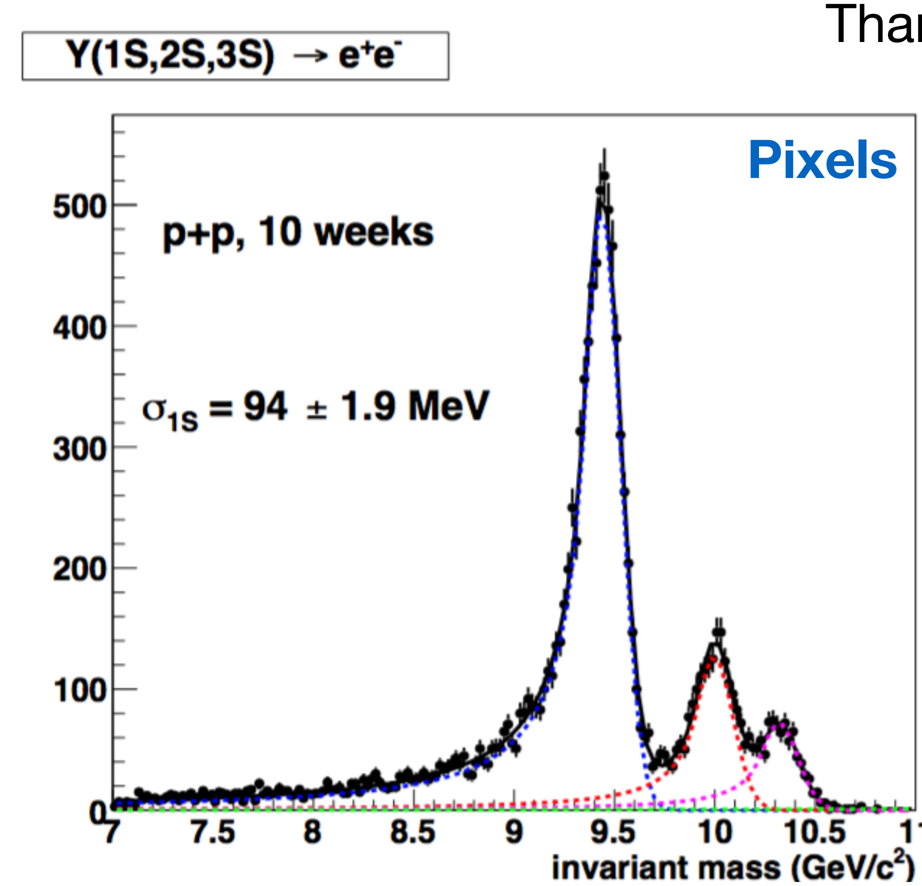
Optimizations between track position requirements and pattern recognition could force the outer layer out farther, depends on outer tracker design

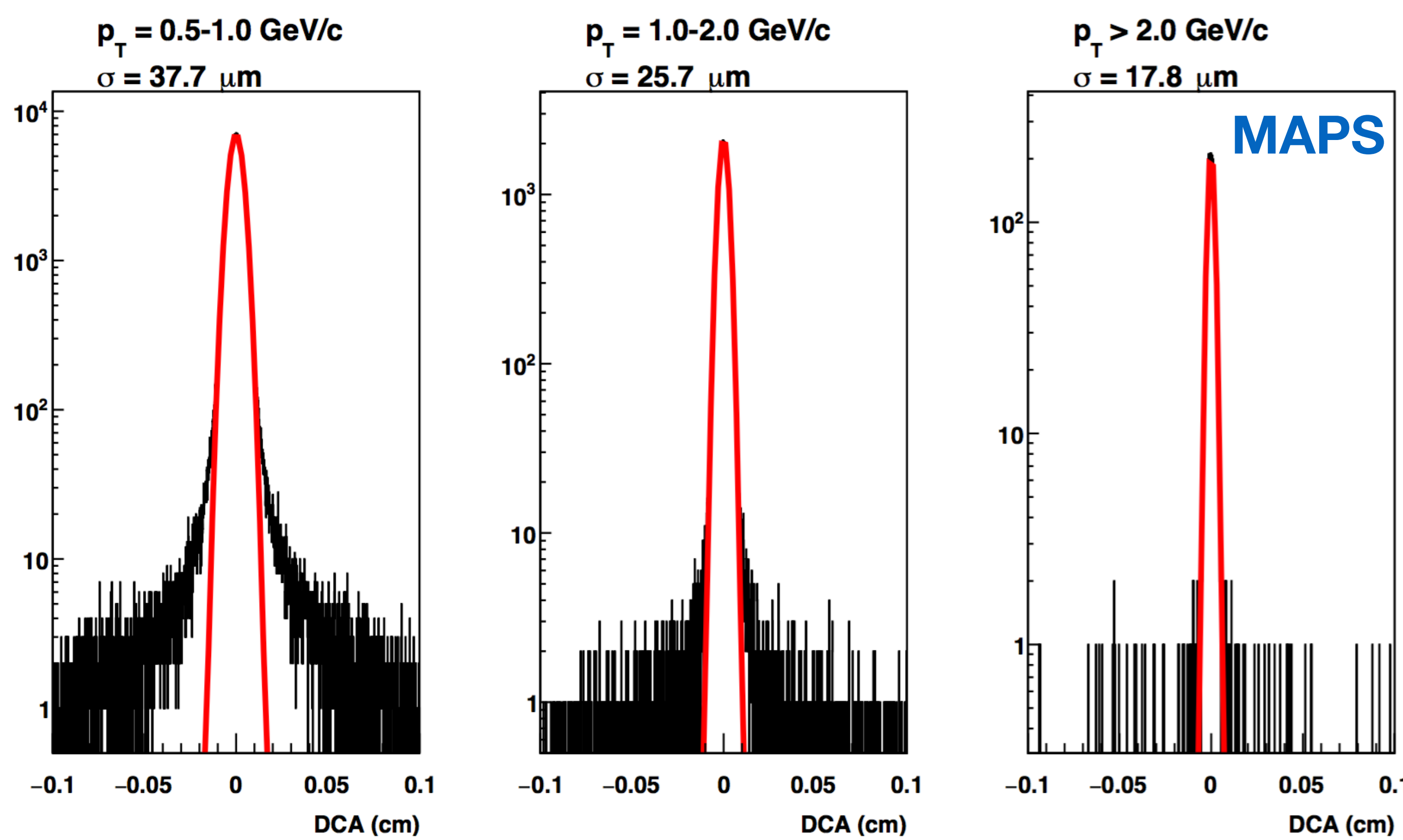
We started with the more compact (2.4,4,6) version…

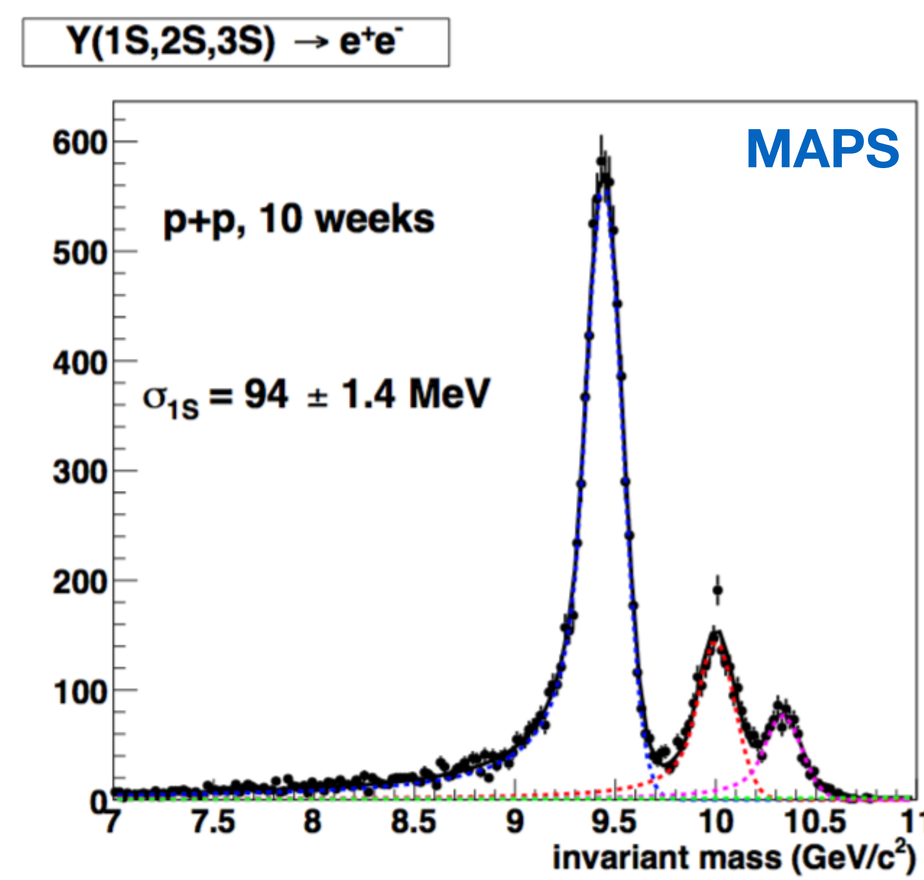
pCDR Performance Plots

Thanks TF!









Missing Detector Requirements

What does our Proposal and pCDR say about b-jet id:

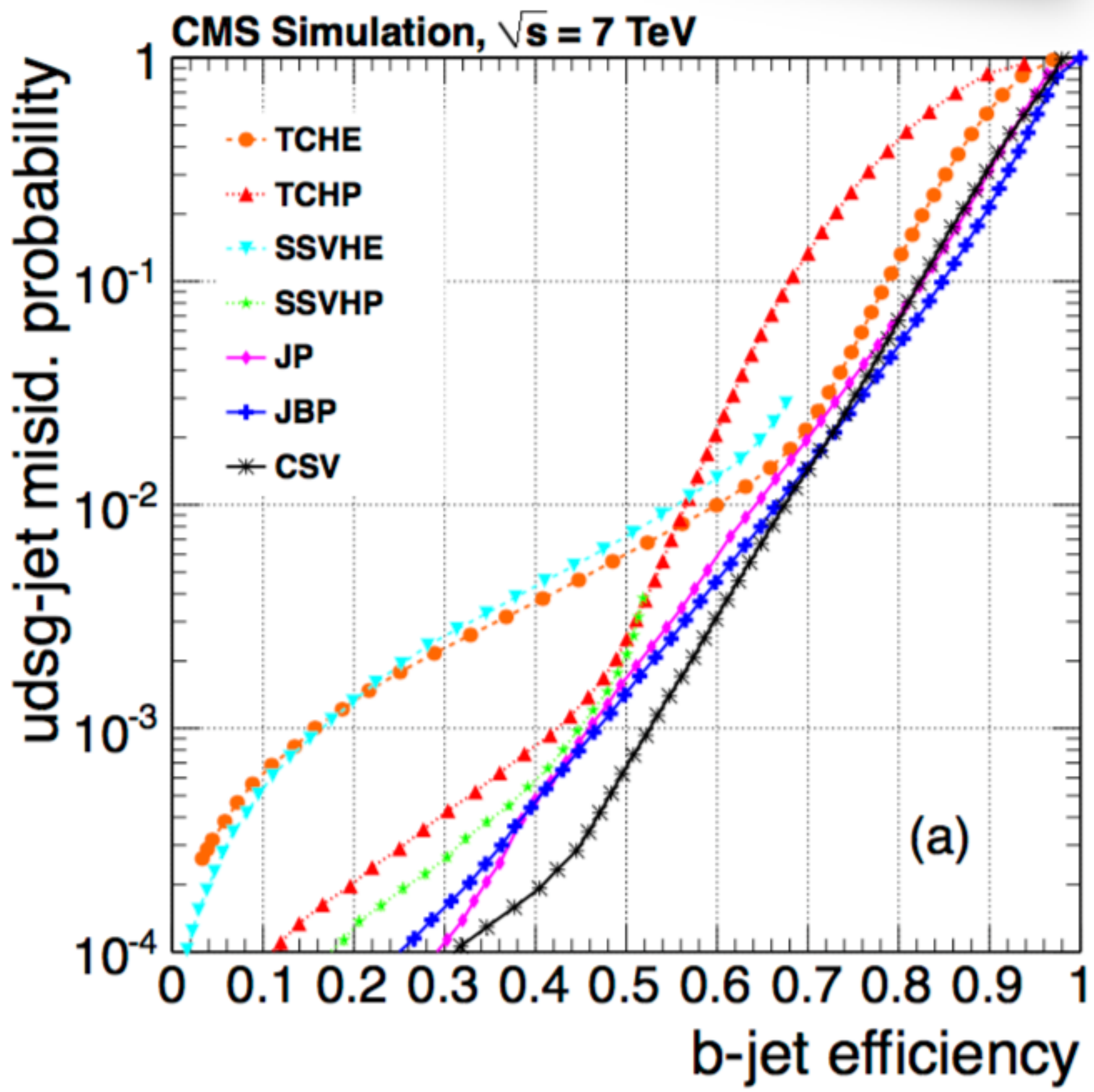
Heavy quark jets The key to the physics is tagging identified jets containing a displaced secondary vertex

- precision DCA (< 100 microns) for electron $p_T > 4$ GeV/c
- electron identification for high $p_T > 4$ GeV/c

The current spec doesn't define a purity/efficiency requirement and focuses only on the semi-leptonic channel for some bizarre reason.

We will need to add either:
(1) charged particle tracking efficiencies
(3-track counting: ~95% will be needed)
(2) track position resolutions / better IP resolutions
(2nd vertex CMS IP resolutions ~15-30 um)
(multi-DCA needs ~70 um)

Or more generally, we should define a spec for:
(A) B-jet identification purity (contamination) and efficiency requirement
(We argued in April that:
~45% efficiency and ~35% purity in Au+Au would be comparable to CMS)

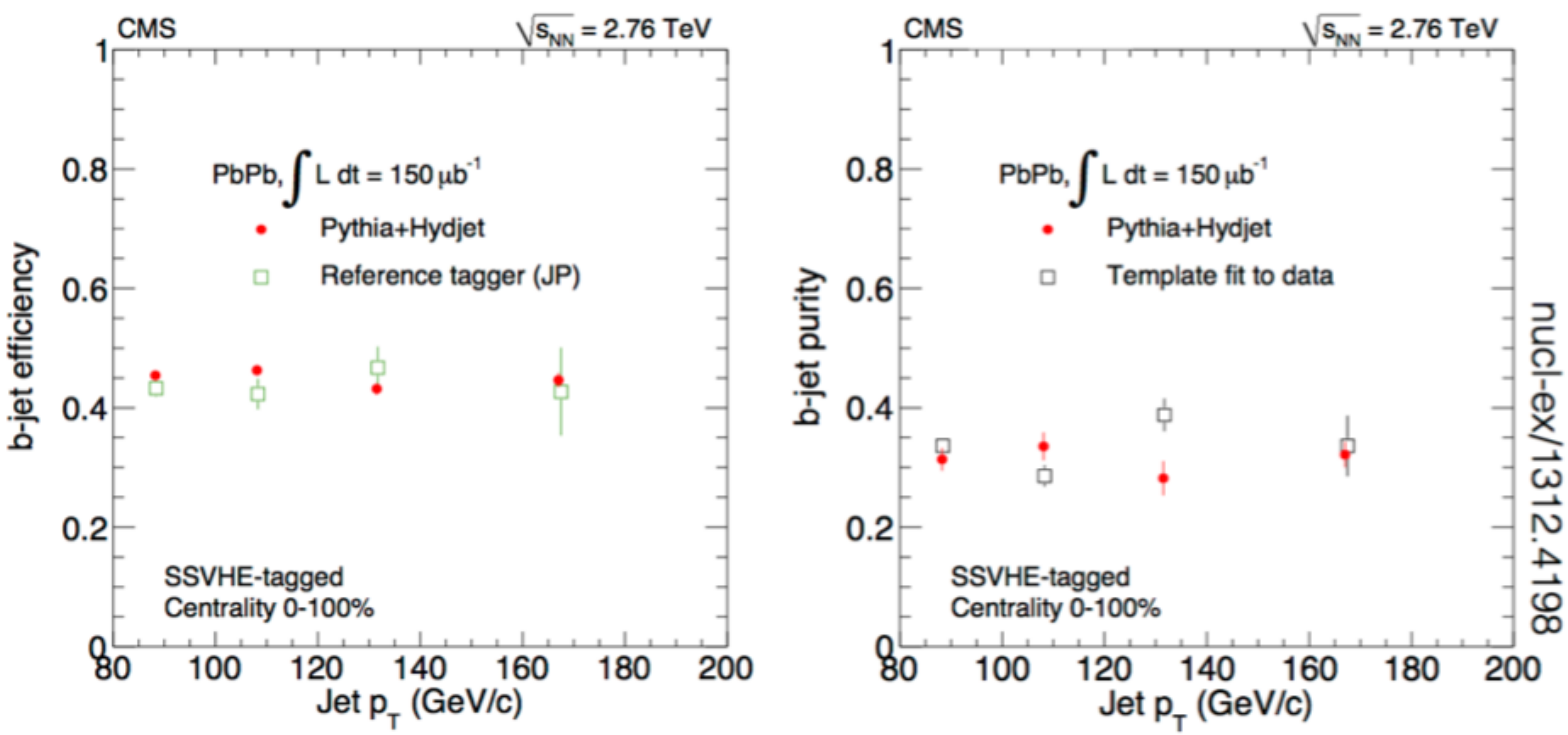


It is a big (unavoidable) job to connect these different methods and the physics to detector requirements but we can use CMS-inspired numbers in the interim

CMS b-jet Performance

from the April Review…

b-jet efficiency and purity in Pb+Pb



<u>*≈45% Efficiency*</u> and <u>*≈35% Purity*</u> in the CMS *b*-jet spectrum in Pb+Pb

➡ comparable to that achievable with 2- or 3-track TrackCounting cuts

Pixel Reuse Pitfalls: Inefficiency

Simultaneous detection with Reused pixels for Track counting methods:

1 track = 33% loss

2 track = 55% loss

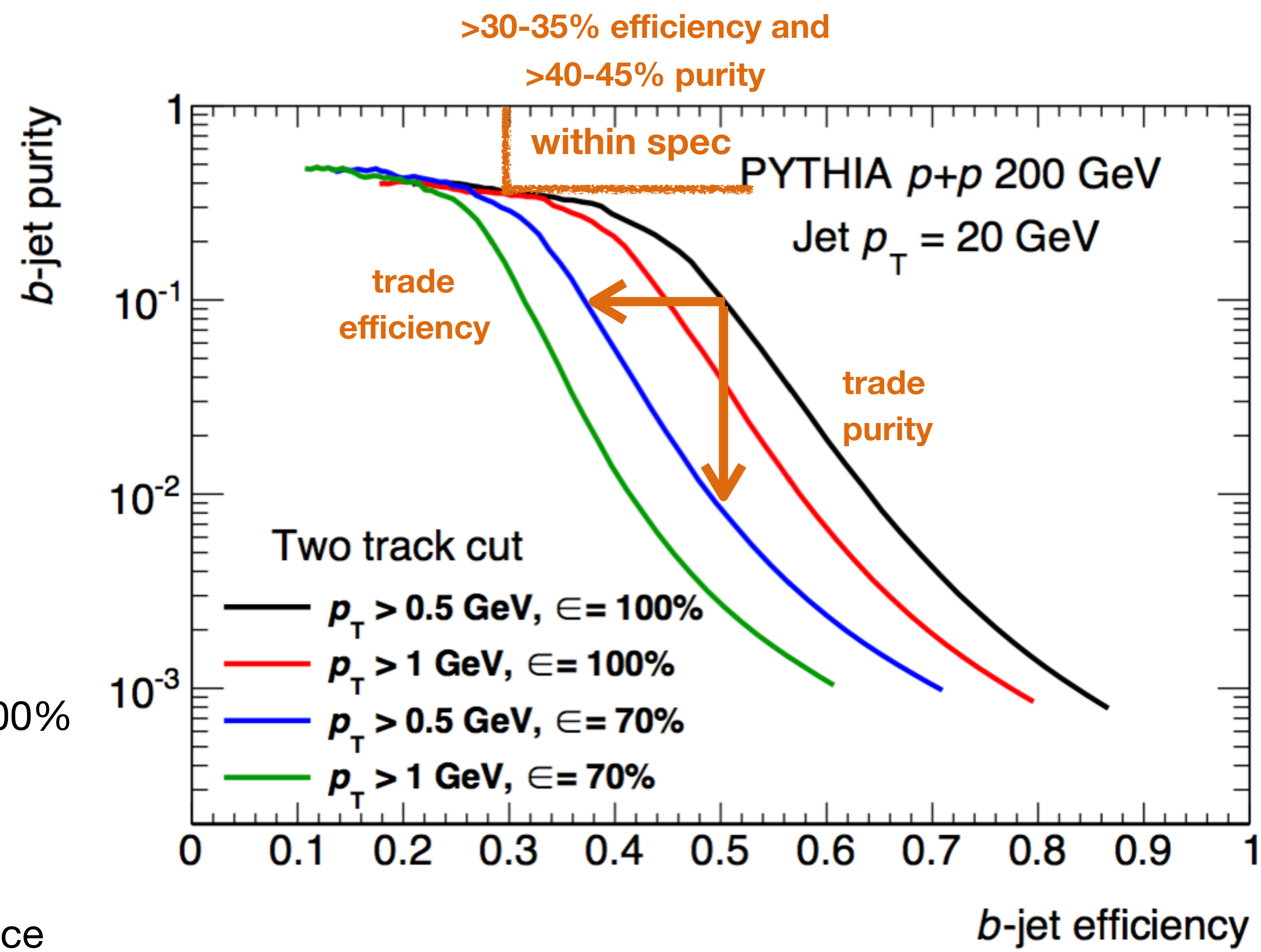
3 track = 70% loss

6-hit tracking + vertex fit will likely work for Upsilons, but not for b-jets

Not too far from spec with 100% efficiency

Could restore purity at lower efficiency, but then acceptance corrections will be come painful

Pretty clear: **Three hit methods will be completely lost, needed to get the largest purities!**



these efficiencies are not included in any sPHENIX b-jet RAA projections

MAPS efficiency for three layers, >99% active => <3% loss

How to Proceed?

(1) Finalize the detector requirements needed to extract the b-jet physics
+ utilize CMS-inspired requirements (manpower would suggest this option)
Suggested numbers: 3D IP resolution of 15-30 um
Single particle efficiency of 95%
Fake rate <2% 1-10 GeV/c

(2) Develop steering macros with all 4 detector combinations
(VTXP vs MAPS) x (Strips vs TPC) using simple geometries (cylinders)
+ start the optimization process on each for the basic parameters

(3) Further develop the tracker software to deal with more complex geometries and tasks
(real-world Kalman, primary tracking through to the vertex, Rave, etc)

(4) Further develop b-jet identification to explore 2nd vertex methods